COUPP Deep Underground Deployment Plan

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The COUPP experiment has recently enjoyed a very successful run of the 4-kg bubble chamber in the MINOS near detector hall at Fermilab. The results of this run have significantly changed some of the assumptions that underlie our previous planning for our efforts with the 4-kg, the 60-kg, and ultimately the 500-kg chambers. This document describes what has changed and how we will adjust our plans in light of the new information.

1.0 Introduction –

"…No matter how fast light travels, it finds the darkness has always got there first[1] …"

The evidence continues to mount that the majority of the matter in the universe is cold, dark, and non-baryonic. A consistent and widely held working hypothesis is that this majority component of matter is the big bang relic density of an as yet undiscovered weakly interacting neutral particle or *WIMP*. Although the nature of the *WIMP* and of the *WIMP*-nucleus interaction is unknown, the phenomenology is straightforward and well understood and predicts *WIMP* dark matter should reveal itself to us directly as an excess of nuclear recoil events over those that can be explained by backgrounds from conventional radioactivity.

The essence of direct detection dark matter experiments is the ability to discriminate true nuclear recoil events from the much more frequent electron recoil events, and there is stiff competition among several technologies to push the frontier of direct detection sensitivity. The extraordinary power of the COUPP bubble chamber technology, in addition to the ability to work with a spectrum of target nuclei, is exceptionally high $\sim 10^{10}$ discrimination between electron and nuclear recoil events. With robust α-discrimination now *all* backgrounds in COUPP have methods to reject them.

2.0 What's New?

"…the best laid plans of mice and men gang aft agley[2]"

The startling success of the recent COUPP 4-kg chamber run[3,4] in the MINOS near detector hall has been a game changer. We have now confirmed that the "wall rate" problem which plagued previous COUPP bubble chamber runs is in fact due to α-emission from natural radioactivity in the quartz vessel walls and that this problem is *entirely eliminated* by the use of a synthetic silica vessel. We have now confirmed that the radon problems that plagued our earlier runs were due to poor choices of fluid handling materials. The elimination of a single *Viton* rubber o-ring from the bubble chamber assembly, and the elimination of *black polyethylene tubing* from our fluid handling plumbing resulted in a fluid contamination of <1 α-event/kg/day, the nominal goal of the coming 60-kg chamber run in the MINOS near detector hall.

The most striking result from the 4-kg chamber run was the observation of robust α-discrimination. With α-discrimination, even the modest cleanliness specification of the

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[1] *Terry Pratchett (English Writer, b.1948)*
[2] *Robert Burns, "To a Mouse," November, 1785*
[3] *"COUPP progress report: results from the 4kg test chamber," C. Eric Dahl (Univ. of Chicago), Ninth UCLA Symposium on Sources and Detection of Dark Matter and Dark Energy in the Universe, Feb 24-25, 2010.*
[4] *"New Dark Matter Limits from COUPP," Jeter Hall, Fermilab Joint Experimental Theoretical Seminar, March 19, 2010.*

4-kg chamber was sufficient to attain new, world's best limits on spin-dependent *WIMP*-nucleus interactions. The limitation of the recent 4-kg run was the comparatively shallow 300 MWE MINOS site. At that depth, the 4-kg chamber was observed to be limited by cosmic induced neutrons which punch through our veto/shielding array.

A 4-kg chamber run in a deep site will improve our world-best sensitivity to spin-dependent *WIMP*-nucleus scattering, and it will improve our understanding of the α-discrimination. If the α-discrimination is as large as we expect, and if we encounter no other unexpected limitations, then the 4-kg chamber in a deep site will be competitive with CDMS for spin-independent *WIMP* limits.

Knowing what we now know, a new path is clear. We need to:

a) *deploy* the 4-kg chamber to a deep underground site. This will extend our physics reach and improve our understanding of α-discrimination.
b) *complete* the installation, commissioning, and evaluation of the 60-kg chamber in the MINOS site and evaluate α-discrimination in the larger device
c) *deploy* the 60-kg to a deep underground site. This will further extend our physics reach.
d) *initiate* an aggressive R&D effort to fully exploit the acoustic α-discrimination
e) *proceed* with the design of a 500 kg experiment

3.0 Coherent Plan for the 4-kg and 60-kg Chambers in a Deep Site

The 4-kg chamber has already demonstrated the world's best sensitivity for spin-dependent dark matter interactions. This sensitivity can be improved by two orders of magnitude by doing no more than moving the chamber to a deep site. It is noteworthy that if the α-discrimination of the 4-kg chamber is as large as we expect, then even this small device can be competitive with CDMS and XENON10 for spin-*independent* WIMP-nucleus interactions and will leave the competition orders of magnitude behind for spin-*dependent* direct WIMP searches. When it is deployed deep the 60-kg would then overshadow the 4-kg and extend this sensitivity even further. The spin-*independent* physics reach of 4-kg and 60-kg runs in a deep site is shown in Figure 1 and the spin-*dependent* reach is shown in Figure 2. The duration of the runs are indicated and it is assumed that the combination of radio-purity and acoustic alpha rejection enable each run to be background free.

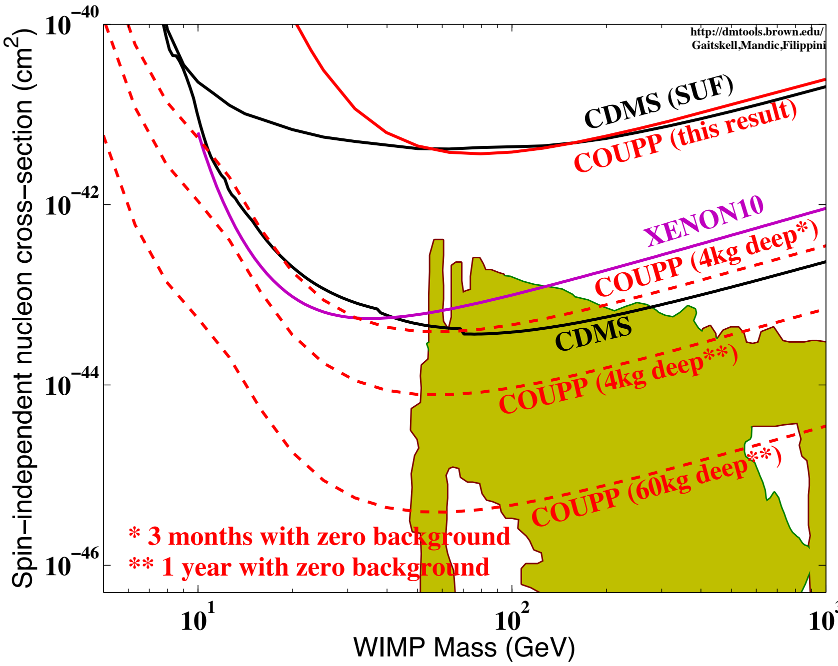

Figure 1: The projected spin-independent physics reach of the COUPP-4kg and COUPP-60kg bubble chambers operating in a deep site.

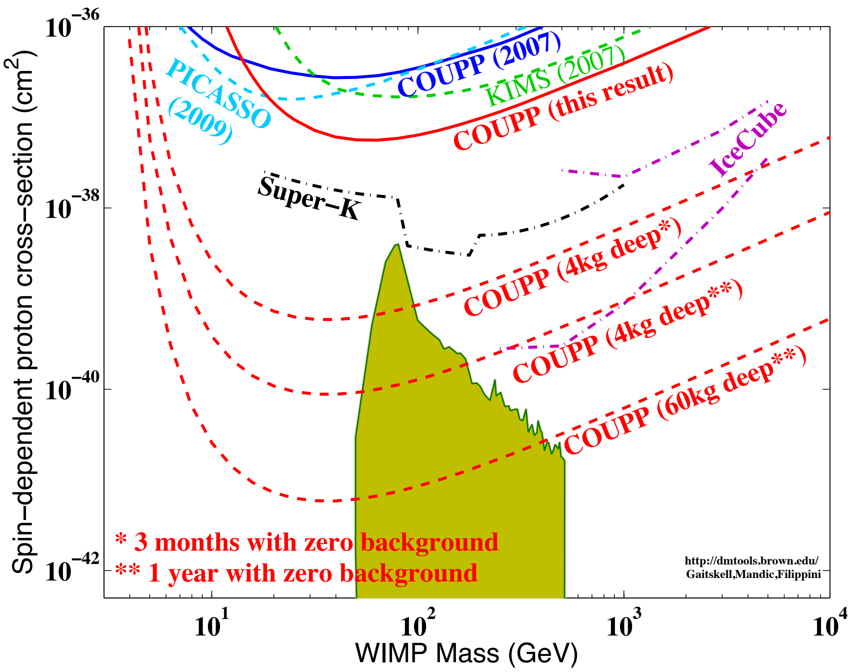

Figure 2: The projected spin-dependent physics reach of the COUPP-4kg and COUPP-60kg bubble chambers operating in a deep site.

The cosmic ray induced neutron rate in a shallow site limits not only the physics reach of a bubble chamber experiment but our ability to assess α-discrimination. This limitation arises because of the cycling time limit that is intrinsic to bubble chamber operations. In practice, we have determined that reliable chamber operation requires a compression/expansion cycle timing of about 90 seconds per expansion. That limits us to no more than 1000 bubble events per day even at very limited live time. For the best quality data, the rate should be limited to no more than a few hundred events per day. This limits the strength of any calibration source and therefore the purity of any calibration sample. An α-discrimination measurement in the MINOS site would be limited by the un-tagged cosmic neutron rate to be no better than ~100/1. In a deep site, one could dope the chamber fluid with an appropriate concentration of an alpha emitter and easily measure an α-discrimination as high as 10000/1 in a run of modest duration. It should be stressed that the measurement of alpha discrimination is the major long term reason for deploying the 4-kg chamber deep underground quite independent of the physics reach this chamber will have. We would like to test the alpha doping on the 4-kg chamber before implementing a cloned system on the 60-kg. Such testing of alpha discrimination is vital in the event that we do see evidence of dark matter as one would need to prove these dark matter candidates are not alpha decays.

In addition to the very specific need for a precision measurement of the alpha rejection by the 4-kg device in a deep site there are a number of benefits of deploying the 4-kg device to a deep site and running it prior to deploying the 60-kg device to the same site. These benefits are less crisply defined than the alpha rejection measurement, but important nonetheless. They include what we would learn from an extensive 4-kg calibration dataset about the positioning of acoustic sensors. This knowledge may enable us to reconfigure the acoustic sensors on the 60-kg vessel between the NuMI and deep site running. An extensive neutron calibration set taken with the 4-kg would also provide crucial information on our threshold and how it varies with temperature and pressure. This would carry over directly to the 60-kg and inform its run plan.

4.0 Timelines for Deployment of the 4-kg and 60-kg Chambers

"…A goal without a plan is just a wish[5]."

The 60-kg chamber was transported to the MINOS near detector hall on March 29. We will proceed with installation and commissioning and will initiate a series of runs that we expect will continue through the summer. If our efforts with the 60-kg device in MINOS are successful, we will be ready to transport the 60-kg chamber to SNOLab in the fall of 2010 and we could be taking data by early calendar 2011.

We need to redeploy the 4-kg chamber as quickly as possible to have this running contribute to the success of a 60-kg effort at SNOLab. We propose finishing all work on the 4-kg chamber in April-May 2010, transporting the chamber to its new site in June 2010, and taking data from July through the fall of 2010. This timescale would generate valuable information about threshold and α-discrimination in a timely way to inform our

[5] Antoine de Saint Exupéry

preparations for a 60-kg deployment, and it would allow us to extend our sensitivity for WIMP-nucleus interactions.

We have analyzed the possibility of operating the 4-kg chamber further at the MINOS site. The problem with this approach is that the effort to mount the experiment in MINOS is not significantly less than the effort to deploy it at a deep site, either SNOLab or Soudan, and the results would be significantly limited. In the estimates that follow, we will assume that we have adopted SNOLab as our site.

5.0 Effort Required to Deploy the COUPP 4-kg at SNOLab:

The COUPP 4-kg chamber was designed for portability. While not necessarily expecting the degree of success we've enjoyed, we did anticipate the possibility that we would want to move it to a deeper site and the design makes this relatively easy. Assuming that our destination is SNOLab we will not need to transport our liquid scintillator veto. In this case the experiment can be disassembled from a fully operational configuration and prepared for transport in roughly one day. Reassembly at the other end is also one day. It would be relatively straightforward to go from taking data in one site to taking data in another in less than one week. We have deployed this chamber many times now and have considerable experience. The entire experiment is currently deployed in a system test configuration in Lab F. Our assumption is that any additional work on the chamber will occur in Lab F, and that when the time comes we will break down the test configuration, prepare the components for transport, and load them on a truck in Lab F. The entire experiment can be carried in a large pickup truck (somewhat greater than one ton.)

The 4-kg chamber is in need of some repairs and of some modest improvements to the data acquisition and controls software. For the SNOLab site, there are some new engineering approval requirements and work to be done. All of these items are summarized below.

1) Bubble Chamber:
    a. Procure new bellows. Cost $3k. Expected on April 1, 2010.
    b. Remove inner vessel assembly. Disassemble and prepare for parts cleaning at A0 and at Lab 3. 1-technician week effort.
    c. Modify plumbing connections to inner vessel. 2-technician days effort.
    d. Clean components, re-assemble, rinse, evacuate, and leak check. 1-technician week of effort.
    e. Reassemble water distillation equipment in Lab 3 and distill water into the chamber. 1-technician week.
    f. Work on the chamber will start April 1 and should all be completed in April.

2) New Acoustic Transducers:
    a. Preamp cards. Very small effort from PPD EED.

b. Fabricate these at IUSB. Few weeks IUSB effort.
c. Receive these at Fermilab, May 1, 2010.
d. Install on the chamber.
e. This work will start in April with a goal of installing sensors in early May.

3) Site Related Engineering:
   a. Piping Assessment. 1-engineer week effort. Start April 1, 2010. Complete by the end of April, 2010.
   b. Shielding Assessment. Scientist effort. April, 2010. This task is to specify how much passive (likely water) shielding will be needed for a 300-kg-day exposure.
   c. Shielding Design: We'll assume that we start with simple "water box" shielding, i.e. stacking of commercial cubic water containers to form the shield. This requires some support to make the stack stable, and we're imagining that this work will be done at the SNOLab end.

Effort and Resources Summary: We Need:

1) Roughly one technician month of effort in April 2010.
2) Roughly one engineer week of effort in April 2010.
3) Something < $10000 of M&S funding
4) Roughly one technician week of effort in June 2010.

This estimate does not include the actual transport of the equipment.

6.0 Summary:

This document lays out a deep site deployment plan for the COUPP collaboration encompassing both the 4-kg and 60-kg chambers. We would like to deploy the 4-kg chamber deep with all possible speed to set world beating limits on spin-*dependent* dark matter and compete with the best in the world in the spin-*independent* channel. Once the NuMI commissioning period of the 60-kg device is over it will go deep and should quickly overtake the 4-kg in physics reach (see Figures 1 and 2). At this point the 4-kg device will be alpha doped to make the precision measurement of the alpha rejection necessary if dark matter candidates are seen. This modification of our original deep site deployment plans has a modest incremental cost and dramatic potential physics return.